Frequency transposition and the effect of training

Ole Hau[1], Petri Korhonen[2] and Francis Kuk[2]

[1] *Widex A/S, Ny Vestergårdsvej 25, 3500 Værløse, Danmark*

[2] *Widex Office of Research in Clinical Amplification (ORCA), 2300 Cabot Drive, Suite 415 Lisle, IL 60532, USA*

Linear Frequency Transposition (LFT) was introduced recently in a commercially available hearing aid. The Widex Inteo Audibility Extender shifts or transposes a high frequency sound linearly down one octave. This frequency shift can potentially increase speech intelligibility for hearing aid users with severe high frequency hearing losses. Preliminary experiments showed increased audibility of high frequency environmental sounds but little influence on speech understanding. One possible reason for this is that acclimatization or training is needed for this type of signal processing. In this study the effects of training on the identification of phonemes is investigated using normal hearing subjects with simulated hearing loss above 1600 Hz. The subjects were tested using pre-recorded stimuli from the Inteo hearing aid both with LFT and normal amplification. The study was conducted over three sessions on separate dates. Each session included three tests separated by 15 minutes of training. The results show that training significantly increases the ability to use the transposed acoustic cues. It is shown that for both fricatives and stop consonants the identification scores with LFT improved relative to normal amplification. These results indicate that it may be important to use training to derive the optimal benefit from frequency transposition.

INTRODUCTION

Frequency transposition is the term used for signal processing techniques that alters the frequency spectrum by moving information bearing signals from one frequency region to another. In a hearing aid with conventional amplification, some sounds may still be inaudible because of physical limitations, severe damage to the cochlea or even dead regions. Frequency transposition can potentially be beneficial in these situations, by shifting information from an unaidable into an aidable frequency region. The question that arises with this type of signal processing is "Could there be a potential speech intelligibility benefit, because high frequency speech cues are made available?"

Linear frequency transposition (LFT) was recently introduced in the Widex Inteo hearing aid. The feature is called Audibility Extender and shifts or transposes a high frequency sound linearly down in frequency.

LFT in this hearing aid has been shown to be beneficial for the audibility of high frequency environmental sounds, but no overall benefit for more complex signals like speech has been observed after initial hearing aid fitting with LFT (Kuk *et al*, 2006). One possible reason for this is that acclimatization or training may be needed to be

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able to accept and interpret the new speech cues.

An experiment was conducted at Widex Office of Research in Clinical Amplification (ORCA) USA to investigate how LFT affects phoneme recognition and if training improves performance.

The experiment was conducted with normal hearing subjects therefore the results may not be directly transferable to hearing impaired subjects; nonetheless it may serve as a guide for how to evaluate LFT on hearing-impaired subjects.

LINEAR FREQUENCY TRANSPOSITION

LFT can be described in the following steps.

1. A source region in the frequency domain is selected and defined by a start frequency, 2500 Hz in Fig. 1, top-left. The octave below the source region is the target region where the transposed sound will be shifted.
2. This algorithm selects a most intense peak in the source region (Fig. 1, top-right) and transposes or shifts the frequency spectrum so that this peak is one octave lower in frequency (Fig. 1, bottom-left). This places the peak in the target region.
3. The transposed frequency spectrum is band-pass filtered so it does not contain frequencies outside the target region and is mixed with the untransposed signal up to the source region 2500 Hz (Fig. 1, bottom-right).

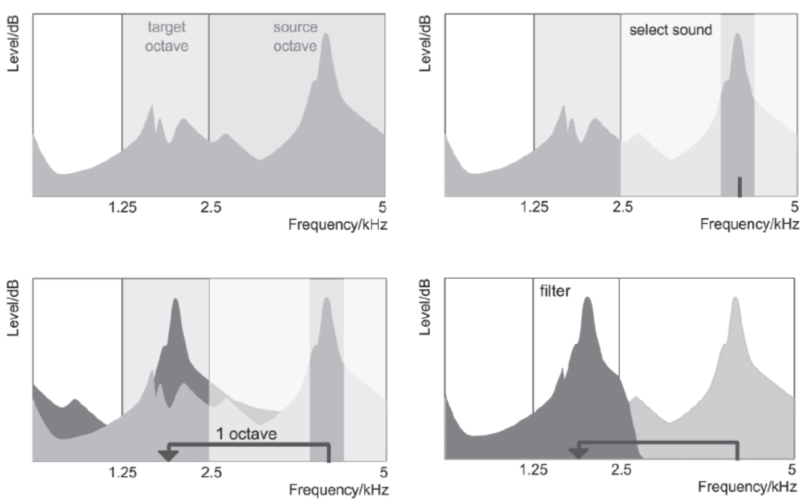

Fig. 1: Linear frequency transposition in 4 steps (Andersen, 2006).

METHOD

A total of seven normal-hearing native English speakers, aged 18-24, participated in the study as test subjects (6 females, 1 male). They all visited the test site at three separate dates completing their tests within 8 days. During each visit, the subjects completed three syllable identification tests, separated by two 15 minutes training sessions on the transposed test stimuli. In the test, the recorded stimuli were presented through headphones.

Stimuli

Stimuli used in this study consisted of the following 31 speech sounds (22 consonants, 9 vowels) found in the English language:

Voiced sounds used are

a. Vowels: /ʊ/: b**u**ddhist; /ɛ/: b**e**d; /ʌ/: b**u**d; /æ/: b**a**d; /i/: b**ea**d; /u/: b**oo**ed; /ɝ/: b**ir**d; /ɔ/: b**aw**d; /ɑ/: b**o**dy.

b. Nasals: /m /: **m**ap; /n /: **n**ap.

c. Stops: /b/:bit; /d/: **d**in, /g/: **g**ut.

d. Affricate: /dʒ/: **j**eep.

e. Approximants: /w/: **w**e; /ɹ/: **r**un; /j/: **y**es.

f. Lateral approximant: /l/: **l**eft.

g. Voiced fricatives: /v/: **v**at; /ð/: **th**en; /z/: **z**ap; /ʒ/: mea**s**ure.

Unvoiced sounds used are

h. Stops: /p/: **p**it; /t/: **t**ap; /k/: **k**it.

i. Fricatives: /s/: **s**it; /ʃ/: **sh**ould; /θ/: **th**at; /f/: **f**at; /ch/: **ch**eck.

For vowels the stimuli are constructed by coupling the vowel with /b/ in front and /d/ at the end (CVC context ex. bed). For consonants the stimuli are constructed by coupling the consonant with vowels /i/, /a/ and /u/ (VCV context ex. isi , asa and usu).

All the syllables were spoken by a female, native English speaker, and recorded in a low-noise level free field environment in the ORCA lab. After the initial recordings, the stimuli were played through a single loudspeaker placed 1 meter in front of a Widex Inteo IN-9 hearing aid connected to a 2-cc coupler. The output of the hearing aid was recorded using two different hearing aid programs one with LFT ON, and one with LFT OFF. In both programs thresholds used to specify hearing aid gain were set to 20 dBHL at/and below 1000 Hz, 50 dBHL at 1250 Hz, 70 dBHL at 1600 Hz, 90 dBHL at 2000 Hz and higher.

LFT was done with two source regions, first source region from 1600 to 3200 Hz and second source region from 3200 Hz to 6000 Hz. Both source bands transposed sound to the 800 to 1600 Hz octave.

A loss of high frequency information is simulated by low pass filtering (FFT filter, 0 dB attenuation to 1550 Hz and 90 dB attenuation from 1650 Hz).

Identification test

In the syllable identification task, consonants and vowels were tested separately. All the stimuli for each test condition (LFT ON/OFF) were played one at the time in random order. Each LFT ON/OFF condition was tested separately. The test subjects were asked to identify the syllable by clicking (using a mouse) on the appropriate button on a computer screen. Buttons for all the stimuli used in the test were shown on the computer screen at the same time. The test subjects could select from any of the possible answers. After each answer was given, the next syllable was played automatically after a 1 second pause. Each syllable was presented twice in a test, amounting to 44 identifications for consonants and 18 for vowels. (2 x 22 consonants, 2 x 9 vowels). Each of the /i/, /a/ and /u/ VCV stimuli were interchanged during visits, so the consonant stimuli were not the same on each visit.

Training

In the training sessions the test subjects were given an opportunity to listen to LFT-processed material with information about the phonemes' identities. Test subjects were also told which phonemes they made mistakes on during the previous test.

The subjects used training software where they could select sounds and listen to them using buttons on a computer screen. The subjects could play each sample as many times as they wished. However, the duration of the training was limited to 10 minutes for consonants and 5 minutes for vowels in each training session.

RESULTS

The resulting overall consonant identification score as a function of visits and tests (Fig. 2 - left) show no effect of LFT ON relative to LFT OFF. However the results show that there is an overall increase in performance for the identification task of 25% for the LFT OFF condition and 27 % for the LFT ON condition from the first visit without training to the last visit.

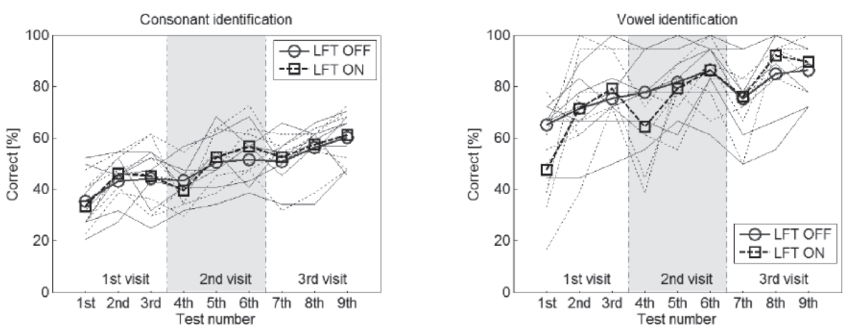

Fig. 2: Overall consonant identification and overall vowel identification. Individual results shown with thin lines. Solid lines show results for LFT OFF condition and dashed lines show results for LFT ON condition.

Vowel identification (Fig. 2 - right) shows a difference between LFT ON vs. LFT OFF.

For the initial test, prior to which the subjects had no training, the subjects performed 17 % worse in the LFT ON condition. This gap is, however, closed only after a single training session. Also there seems to be a tendency toward a drop in score between visits for the LFT ON condition. This can perhaps be attributed to the fact that the subjects were not exposed to transposed sounds between visits or prior to the first test. This indicates that there is an effect of training.

Segmenting consonants into subgroups such as stop consonants and fricatives can also reveal the effect of training. The left panel of Fig. 3 shows the identification score for stop and fricatives consonants. Here it is shown that there is a benefit for this group of consonants in the LFT ON condition; 7 % at the final test. This effect is especially clear when only considering the voiceless stop consonants and fricatives; 13 % at the final test (Fig. 3, right).

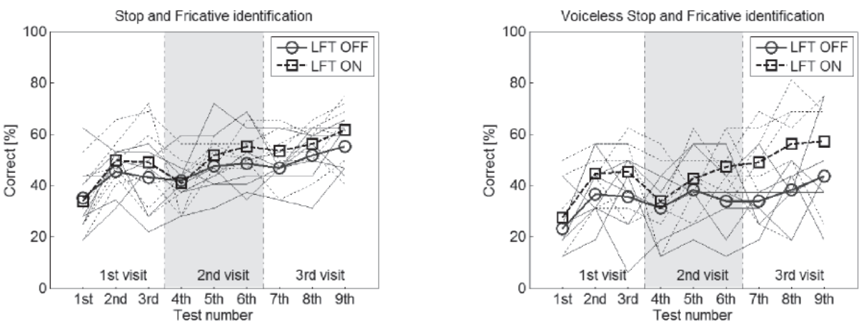

Fig. 3: Overall stop and fricative identification and overall voiceless stop and fricative identification. Individual results are shown with thin lines. Solid lines show results for LFT OFF condition and dashed lines show results for LFT ON condition.

DISCUSSION

It should be stressed out here that the results cannot be directly transferred to hearing impaired subjects. The results shown here are for normal hearing subjects with a simulated high frequency “hearing loss” and with a limited amount of training.

Linear frequency transposition (LFT) did not affect the overall score for consonant identification, even with this very low frequency source and target octave. However, LFT improved subjects’ ability to identify fricative and stop consonants (especially voiceless). Vowel identification was affected, but subjects seem to adapt to the new cues quickly after training in this task.

These findings show that even though the overall score for phoneme identification can be the same for the LFT on/off conditions, there can be big differences, in identification of individual phonemes. This leads to the indication that it is important to use training to derive the optimal benefit from frequency transposition.

The experiment was designed with frequency transposition at low frequency, in the formant region of most voiced phonemes, where we would anticipate transposition to have the biggest negative impact on speech perception. The results, however, do not show an overall negative effect on the perception of phonemes as long as training is provided. This gives a hope that perhaps with higher start frequencies, where voiced speech is not affected to the same degree, there could be an even higher overall benefit. Also different fitting strategies, training techniques and acclimatisation with hearing impaired subjects could realise higher overall benefit in the future (Kuk *et al*, 2007a and Kuk *et al*, 2007b).

REFERENCES

Andersen, H. (**2006**). ”Audibility Extender - So the “Dead” (Region) May Hear”, Integrated Signal Processing. A new standard in enhancing hearing aid performance,” Widex Inteo, 20-22.

Kuk, F., Korhonen, P., Peeters, H., Keenan, D., Jessen, A., and Andersen, H. (**2006**). “Linear Frequency Transposition: Extending the Audibility of High-Frequency Information,” The Hearing Review, **13**(10), 42-48.

Kuk, F., Keenan, D., Peeters, H., Korhonen, P., Hau, O., and Andersen, H. (**2007a**). “Critical Factors in Ensuring Efficacy of Frequency Transposition Part 1: Individualizing the start frequency,” The Hearing Review, **14**(3), 60-67.

Kuk, F., Keenan, D., Peeters, H., Lau, C., and Crose, B. (**2007b**). “Critical Factors in Ensuring Efficacy of Frequency Transposition Part 2: Facilitating Initial Adjustment,” The Hearing Review, **14**(4), 90-96.